Radiation Effects of Proton Particles in Memory Devices

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ABSTRACT—In this letter, we study the impact of single event upsets (SEUs) in space or defense electronic systems which use memory devices such as EEPROM, and SRAM. We built a microcontroller test board to measure the effects of protons on electronic devices at various radiation levels. We tested radiation hardening at beam current, and energy levels, measured the phenomenon of SEUs, and addressed possible reasons for SEUs.

Keywords—Radiation effect, single event upset, single event effect, memory device, proton.

I. Introduction

Heavy ions, energetic protons, and electrons produced by solar eruptions are trapped in the near-Earth environment. In the trapped regions, plasma is a low energy component of the charged particles, which has less than 0.1 MeV. Radiation-hardened electronic parts are used for satellites and nuclear power plants since there are various radiation particles in space and other highly radioactive environments which may induce a radiation effect called single event upsets (SEUs) in electronic systems.

Our focus here is to study SEUs as a radiation effect on memory devices. We created a test environment using a proton particle accelerator at KIRAMS (Korea Institute of Radiological Medical Sciences) and implemented the microcontroller test board which we have developed.

II. Radiation Effects

Generally, there are two radiation types: particle radiation and photon radiation. In particle radiation, the charged particles can be protons, electrons, α particles, ions, or neutrons.

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Unlike total dose radiation [1] which causes gradual global degradation of device parameters [2] and dose-rate radiation which causes photocurrents in every junction of a circuit, a single event interaction is a very localized effect and can lead to a seemingly spontaneous transient within a region of the circuit.

The total ionizing dose that impinges on semiconductor devices can be caused in a natural environment such as Van Allan Belt [3], which is a region of charged particles trapped by the earth's magnetic field. In most cases, Van Allen protons and electrons are the primary radiation problem for spacecraft. The maximum proton flux is about 1×10^4 protons/cm^2, which converts to 0.001 rad/s [4]. The electron flux is around 1×10^{10} electrons/cm^2 [3], which changes to about 0.028 rad/s at the worst altitude. In the event that a solar flare occurs, the proton flux may increase by several orders of magnitude for a few days. The total ionizing dose can also be caused by x-rays and gamma rays engendered by a nuclear weapon detonation.

The upset rate calculation depends on knowing the linear energy transfer (LET) dependence of the device sensitivity. The result of an SEU test provides a user with the information needed to accurately predict the SEU rate. The basis of any SEU rate calculation is the cross-section (σ) as a function of LET and the LET is the $LET_0 \sec\theta$. The LET_0 is defined as the LET at normal incidence to SRAM and EEPROM.

The cross-section is given by

$$\sigma = (N/F) \sec\theta, \tag{1}$$

where N is the number of errors, F is the fluence, and θ is the angle of incidence of the particle beam.

In this work, upsets were observed until latch-up occurred. In fact, SEU is the most common type of single event effect.

III. Implementation of Microcontroller Board

1. Hardware Structure

The microcontroller test board, as shown in Fig. 1, can be thought of as a small computer. The basic structure includes input, output, control, and memory equipment. The operation and control equipment comprise the CPU. The circuit of the microcomputer [5] executes the processor functions with an ATmega 128 chip, 74HC573 [6] as a latch dividing address and data, an EEPROM controlling processor, standalone SRAM (HY62CT08081E) or EEPROM (AT28C16) to be irradiated by energetic protons, 8255 to extend the bus line, and a 7447 to count the time and the number of upsets. Commands come to the CPU through the input equipment and are carried out. After the microcontroller test board completes the operation, it sends the results to the output equipment.

2. Software Structure

A. Initializing Functions and Memory Read/Write Routine

- Set control commands on 8255 programmable peripheral interface using ports A, B, and C with 8 bits for output functions.

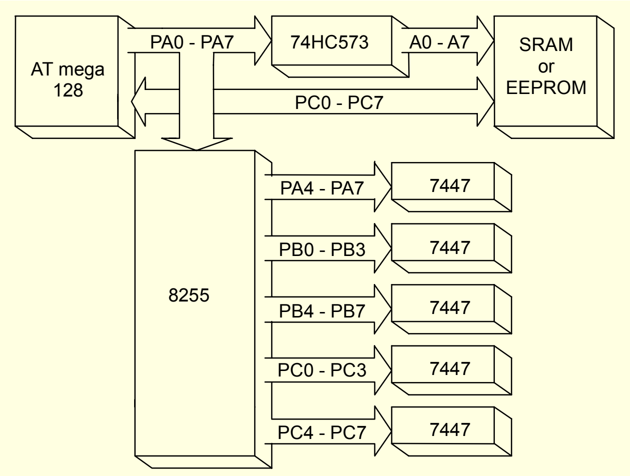

Fig. 1. Block diagram of a microcontroller test board.

Fig. 2. Photo of the testing controller board.

- Set the data table to control FND.
- Control the time needed for delay function.
- Initialize the RAM, and set the functions to read and write data at the RAM or EEPROM.
- Count the number of upsets by controlling command for reading and writing data at the RAM.

B. Main Functions

- Assign parameters.
- Initialize functions for 3 kinds of devices: AVR, RAM, and 8255.
- Set control commands for display on FNDs

3. Signal Flow of Block Diagram

A. Power on Initialization

The voltage of 5 V is applied; all other devices including CPU of AVR are initialized.

B. Peripheral Initialization and Memory Read/Write Routine

The 8255, 7447, and FND carry out the display function while the SRAM or EEPROM in standalone to be irradiated by energetic protons carry out read and write functions continuously.

C. Upset Routine

Three thousand random bits of 1 or 0 data are loaded onto the memory component, and the software program is run to count upsets of one-to-zero or zero-to-one in the SRAM or EEPROM for 300 seconds, and the number of upsets is shown in the FND.

IV. Experiment and Results

To experimentally study SEUs of the SRAM and EEPROM, the cyclotron accelerator at KIRAMS was utilized. The maximum energy of the accelerator was 50 MeV and the beam current was 3 nA to 20 µA. A commercial-grade Hynix SRAM and an ATmel EEPROM, attractive candidates for space applications, were irradiated with energetic protons to study resulting SEUs. A monitor with remote camera equipped to check upsets was put outside the experiment room. The SRAM and EEPROM were handled by suitably complex software during irradiation.

The testing microcontroller board shown in Fig. 2 was manufactured by researchers at Woosong University, Korea. It is surrounded by plumbum blocks to protect the proton particles of about 1×10^{13} particles/cm^2.

When the energy of 30 MeV and a beam current of 1 µA was irradiated, the number of upsets was up to a maximum of 8 for 290 seconds. The number of upsets increased exponentially as

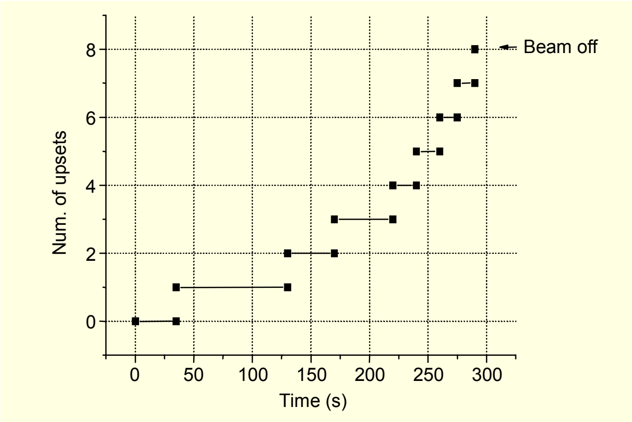

Fig. 3. Number of upsets (1→0) under 30 MeV energy and 1 μA beam current.

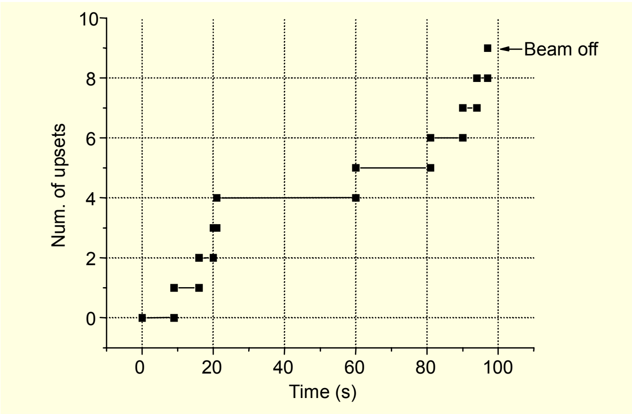

Fig. 4. Number of upsets (1→0) under 30 MeV energy and 2 μA beam current.

shown in the exponential curve in Fig. 3.

When the energy of 30 MeV and the beam currents of 2 μA and 3 μA were applied, the number of upsets reached 9 for the shorter times of 93 and 54 seconds as shown in Figs. 4 and 5, respectively. When the beam current was greater than 3 μA, the SRAM was latched up. This indicates that the threshold level is 3 μA. Also, it was observed that as the beam increased, the upset time decreased drastically.

From Figs. 3 and 4, it may be noted the upset time was very long and the penetration time to upset the content was nonlinear as the beam currents were just 1 μA and 2 μA, respectively, though the proton energy remained the same at 30 MeV.

Figure 5 reveals that 8 upsets were reached in just 50 seconds for the 3 μA beam current compared to 1 μA beam current for which it took 6 times as long (about 290 seconds). This is shown in Fig. 3.

Upsets are directly related to the beam current which settles linearly [7] as it increases. However, in the EEPROM test which was carried out under the same conditions as the SRAM test, the same number of upsets did not occur.

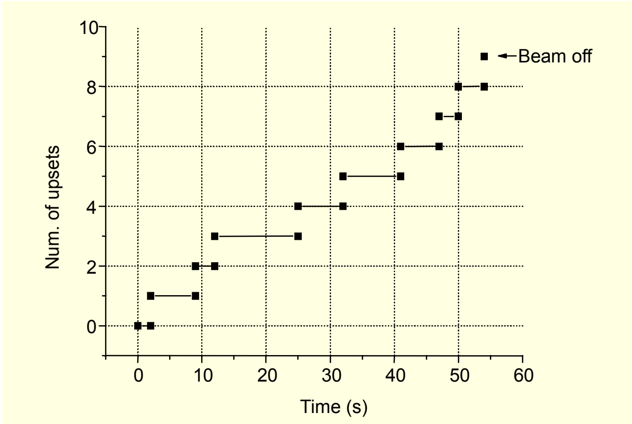

Fig. 5. Number of upsets (1→0) under 30 MeV energy and 3 μA beam current.

V. Conclusion

The controller board was implemented with an ATmega 128 processor. When the proton energy of 30 MeV at a beam current of 3 μA was applied from the cyclotron accelerator of KIRAMS to the commercial Hynix SRAM, the number of upsets increased linearly as shown in Fig. 5, which satisfies (1). Moreover, the number of upsets was not as high in the ATmel EEPROM test under the same energy and leakage current as in the SRAM test since the resin of the EEPROM is thicker than that of the SRAM.

The proposed test method provides a simple self-inspection program for interface and operation during proton irradiation. The results turned out to be quite successful. Our experiment establishes the basis for a test method for SEUs, one of the most important issues in radiation-hardening technology.

References

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